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ABSTRACT

The paper explores the needs of gifted students with exceptional interests and talents in science. General characteristics of gifted students are listed, as are characteristics of the gifted in science (including questing, personal drive, and an enjoyment of numbers). A multidimensional gifted identification process is reviewed, and the lack of instruments for identifying the gifted in science is noted. Three principles of differentiating the science curriculum for the gifted are described: higher cognitive thinking skills, processes of learning/thinking, and formal operational schemes. Criteria for evaluating science lessons according to these three principles are listed. The paper concludes with three examples of model science lessons for the gifted: determining density and evaluating density investigations; investigating starch location in plants and implication for nutrition; and understanding phosphorus and its effect on water quality. (CL)

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# DEVELOPING GIFTED PROGRAMS IN SCIENCE

## Introduction

The National Science Teachers Association (NSTA) position statement on science for the 1980's details the influence of science and technology on the welfare of our society (Berkheimer et al, 1982). Today more than ever educators need to provide experiences designed to encourage the development of scientifically literate individuals. In making recommendations on how schools should accomplish this task, NSTA has suggested that the needs of those with exceptional interests and talents in science be acknowledged and met.

The purpose of this paper is to explore the field of gifted education and discuss implications and applications for science educators. Of specific interest will be discussing the characteristics of the gifted in science, how gifted science students can be identified, strategies for differentiating science instruction for the gifted, and providing model lessons that integrate these principles into instructional activities.

## General Characteristics of the Gifted

While characteristics of the gifted are well documented in the literature, a brief review will serve to set a frame of reference for later discussions. The chart below lists general characteristics of the gifted.

Characteristics of the Gifted Child
- General -

| | |
|---|---|
| High I.Q. | Heavier than average |
| High ideals | Coordinated |
| Reads a lot | Reads well |
| Trustworthy | Interested in the environment |
| Large vocabulary | Superior mental health |
| Analysis thinking | Unusual imaginations |
| Expresses ideas clearly | Self-critical |
| Taller than average | Socially adjusted |
| Abstract thinking | Better physically developed |
| Healthy | Reaches puberty early |
| Evaluative thinking | Better memory |
| Hypothetical-deductive reasoning | Synthesis thinking |
| Sets high personal standards | Understands cause-effect |
| Undergoes bone ossification early | |

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Inspection of this list will cause the eyebrows of even the most liberal gifted educators to rise. However, recent research (Freeman, 1979) identified a number of these characteristics as myths. Freeman found gifted children had fewer but older friends and were not taller than their peers. Other myths related to a lack of first-born children and only children among the gifted, a lack of differences in behavior between gifted and regular children, and no differences as reported by parents in raising gifted children. The discrepancies between characteristics of gifted children as described by parents, teachers, and others, and those substantiated by recent research, suggests that lists of characteristics ought not be used as identification criteria. Paul Brandwein confirmed this position by providing the following caution regarding the use of his list of gifted characteristics: "While no one child possesses all these characteristics, the possession of several may indicate a potential" (Brandwein, 1975, p. 7).

Characteristics of the Gifted in Science

Characteristics of the gifted in various disciplines are described throughout the literature. Among these descriptions can be found characteristics of the gifted in science. Although these descriptions can be useful in learning to recognize the gifted science student, there is a danger that educators will use the characteristics as criteria for identifying, comparing, or eliminating students. One must keep in mind that any list of characteristics of gifted students relates in a general sense to the designated group. Certainly there will be individual students who do not match all the characteristics. The implication for educators is to use a list of characteristics to gain a holistic sense of the students as a group.

Ann Roe's book, The Making of A Scientist is perhaps one of the most significant early discussions of scientists and their personalities (Roe, 1953). In addition to such characteristics as a happy disposition, a strong ego, and emotional stability, Roe included the characteristics of questing. This term is often used to describe the gifted student in science. A questing student is one who is dissatisfied with explanations of phenomena and events that they encounter. Others have described these students as possessing a searching and inquiring attitude, unwilling to accept explanations about things without scientific proof, and interested in getting answers to questions suggested by their work and by their teachers (Witty, 1958; Marshall, in Fliegler, 1961; Kopelman, 1977).

A second characteristics that is closely related to questing is personal drive. Kough and DeHann (Kough, 1960) clarify this by describing the student with scientific ability as one who is willing to spend time investigating a topic over and above that which is ordinarily needed and spends time on special projects of his/her own choice.

A third characteristic relates to the scientifically gifted student's investigative nature; they conduct investigations despite obstacles and failure. It is not uncommon to find these students attempting to solve problems for which

they do not have the proper equipment, materials, or background. However, despite these inadequacies, the gifted in science persist in their inquiry.

Marshall (Fliegler, 1961) describes the gifted in science as maintaining a sustained interest in science beginning as early as the pre-school years. In recent reviews of the literature, this sustained interest is described as that of reading scientific and science fiction material, enjoyment of engaging in scientific discussions, a desire to learn the scientific names of objects, and a curiosity about phenomena and cause-effect relationships (Consuegra, 1980; 1982).

A number of articles describe the gifted science student's interest in quantitative relationships and superior ability in using and understanding mathematical concepts (Marshall, in Fliegler, 1961; Brandwein, 1975; Witty, 1958 Kough, 1980). This is one of many characteristics that overlap with the gifted in mathematics (see Consuegra, 1981 for a review of the literature in this area.)

Recent research has shown that the gifted in science exhibit formal operations much earlier than their peers. Of the three skills investigated (hypothetical-deductive reasoning, proportional reasoning, and separation and control of variables) gifted students were shown to exhibit formal operations as early as the upper elementary grades (Keating, 1973; Webb, 1973). This suggests that gifted students who are at or approaching the junior high age might be precocious in other formal operational processes as well.

The chart below is a summary of the characteristics of students who are described as gifted in science.

Characteristics of Students Gifted in Science

The gifted science student:

1. Has an inquiring mind
2. Reads science books
3. Likes science objects
4. Does many projects in science
5. Is intrigued by cause-effect relationships
6. Uses evidence to make decisions
7. Enjoys numbers
8. Forms hypotheses
9. Understands proportions
10. Conducts experiments carefully

(Consuegra, 1982, p. 187)

## Identifying the Gifted

Although lists of characteristics of the gifted are useful in gaining an understanding of the gifted as a group, their use as an identification tool is limited. Tuttle (1978) has outlined a three-step multidimensional identification

process. Such a process is designed to reduce the error that might be associated with individual instruments or a single criterion.

Screening is the first step toward identifying the gifted. The purpose of screening is to establish a pool of students for further examination. Instruments at this level include group test scores, nominations, rating scales, and other measures designed to determine whether the student has potential. At this stage it is important to include marginal students, particularly if they are members of cultural and racial minorities.

Identification is the second step of a gifted identification process and involves a more thorough analysis of each student's potential. Instruments at this level include individualized intelligence tests, case studies, and other measures of exceptional ability. This step results in a group of students that are designated as gifted but who have diverse educational needs.

The final step in a multidimensional gifted identification process is selection. Here interests and proclivities are considered so students are selected for program offerings that are suited to individual needs. Included at this level are measures of aptitude in specific areas, performance on subject-specific achievement tests, and the matching of characteristics to lists of characteristics in the field or subject being considered.

## Identifying the Gifted in Science

Identification of the gifted in specific subject areas is the objective of many gifted identification procedures. Tuttle's multidimensional process makes a provision for accomplishing this end. However, many gifted programs eliminate the general nature of the screening and identification process in favor of subject-specific measures. In a number of cases discussed in the literature, achievement and aptitude instruments constitute a major portion of the identification process (Consuegra, 1980).

Identifying the gifted in science should proceed as any general gifted identification process. Subsequent to the screening and identification phases, students should be evaluated for their specific proclivity in science. Criteria that might be used include high science grades, science teacher recommendations, self-expressed interest in science, exceptional performance on science achievement or aptitude tests, and a science propensity as determined through the use of a scale for assessing science-related characteristics.

Although a number of various instruments are available for selecting gifted students in science (Consuegra, 1980; 1982), there seems to be a lack of scales for evaluating a student's gifted science characteristics. Development and validation of such a scale is the goal of this author. Presently, research is being conducted in this area and initial pilot testing will begin in the near future. The items for this scale will be related to the characteristics of the gifted in science described earlier.

## Differentiating Instruction for the Gifted in Science

The first step toward meeting the needs of the gifted in science center around understanding their characteristics and developing procedures for their identification and selection. Once the students are selected for a gifted science program, attention must be focused on instructional strategies. Experts agree that if programs are to meet the needs of the gifted, the instructional strategies must be based on their differential characteristics (Clark, 1979; Johnson, 1980; Akers, 1982). The implication for gifted science programming is that instruction should be based on characteristics of the gifted in science.

Analysis of the characteristics of the gifted in science suggests that three principles of differentiation are applicable: higher cognitive thinking skills, processes of thinking/learning, and formal operational schemes. Each of these principles and their components are described below. The model lessons that follow illustrate how these principles can be implemented into instructional activities.

Higher Cognitive Thinking Skills--according to Bloom's Taxonomy, thinking can be divided into six processes. Of those processes, analysis, synthesis, and evaluation are regarded as the highest levels of thinking. Analysis involves the examination and breaking down of information into elements so that the relationships between them are made clear. Synthesis is the combining of elements into a new or unique format. Evaluation is making judgements about the value of information. By emphasizing these three thinking skills, students are encouraged to think critically, provide creative responses, and demonstrate a more thorough understanding of what they have learned (Carin and Sund, 1980).

Processes of Learning/Thinking--Components of this principle include problem solving skills, research skills, scientific approaches to investigations, epistomological considerations, the use of logic, quantifying and manipulating data, and evaluating the processes used to solve problems. The emphasis of this strategy is not on gaining information, rather on gaining a better understanding of how knowledge is generated.

Formal Operational Schemes--the formal operational schemes, as described by Jean Piaget, have been shown to be significantly correlated with scientific understanding (Lawson, 1974). While Sund (1976) has described 14 formal operational schemes, the following seem most suitable for science instruction for the gifted: hypothetical-deductive reasoning, separation and control of variables, abstract reasoning, reflexive thinking, combinatorial logic, and proportional reasoning. These schemes are discussed in detail in Piaget for Educators: A Multimedia Program (Sund, 1976). Consuegra (1980,b) also discusses and illustrates several of these schemes.

Science instruction that integrates these principles into units and lessons can be justifiably labeled a gifted science program. Since the principles are based on the characteristics of the gifted in science, Akers (1982) would agree that such a program is likely to meet the real needs of those students. One criticism that is often expressed when principles of differentiation are examined or when differentiated lessons are analyzed is that these strategies and instructional activities are appropriate for many kinds of students, not only the gifted. The problems with this criticism is it implies that gifted educators hold these strategies as exclusively useful for the gifted.

To say that these instructional strategies are only for the gifted is a misapplication of the intention of differentiated instruction. Rather, strategies are chosen because they relate to the characteristics of the intended educational group. It is not implied that there are no applications for other groups. Certainly this view is cogently illustrated in the case of instructional strategies designed for special education populations. A number of special education instructional techniques can be quite useful for other types of students.

## Evaluating Science Lessons for the Gifted

The development of science lessons for the gifted should proceed with consideration of the principles of differentiation discussed above. Upon completion of this process, an evaluation of whether the activities can be justified as appropriate for the gifted should be completed. Criteria for such an evaluation is listed below.

### Principles of Differentiation
### -Science-

1. Higher Cognitive Thinking
   - A. Analysis
   - B. Synthesis
   - C. Evaluation

2. Processes of Learning/Thinking
   - A. Problem solving skills related to original or unique problems
   - B. Research skills
   - C. Collection of original data
   - D. Quantification of data
   - E. Manipulation of data
   - F. Using data to draw conclusions
   - G. Design of investigative processes
   - H. Evaluation of problem solving or investigative processes

3. Formal Operational Schemes
   A. Hypothetical-deductive reasoning
   B. Separation and control of variables
   C. Abstract reasoning
   D. Reflexive thinking
   E. Combinatorial logic
   F. Proportional reasoning

The following section contains three model lessons for the gifted. At the end of each lesson is a rationale for the gifted indicating the specific principles of differentiation that are integrated into the activities. This author firmly believes in the practice of providing such a rationale when any instructional activities are developed. Such a practice requires the curriculum developer to evaluate his/her work and justify the gifted designation for the activities. Others are encouraged to do the same whenever lessons for the gifted are observed, reviewed, or developed.

## Concluding Remarks

NSTA's position statement on science and technology for the 1980's outlines the importance of science education for our society. Although science education is critical for all our children, experts agree that the gifted are ideally suited for making contributions to our technological society. By providing appropriate educational experiences, the gifted will be equipped to fulfill society's, as well as their own, expectations.

Meeting the needs of the scientifically gifted presupposes that the gifted in science are recognized, can be identified, and receive proper instruction. The information in this paper was compiled for just this purpose. Teachers of the gifted, in science as well as other disciplines, have an obligation for providing the kind of instruction that will benefit individual student needs and the needs of our society. By working within the context of learning more about the gifted, developing better procedures for identifying them, and improving instruction so that it is commensurate with their differential needs, the gifted will have an opportunity to fulfill their potential and their role of making contributions to our society.

## MODEL SCIENCE LESSONS FOR THE GIFTED

### I. Determining Density and Evaluating Density Investigations

#### A. General Purpose

The students will learn how to determine the densities of objects, how to evaluate their results, and obtain experience in designing an experimental procedure.

#### B. Objectives

The students will:

1. Determine the densities of various objects
2. Compare the obtained densities with actual densities
3. Calculate the percentage of error for obtained densities of objects
4. Evaluate the process of determining the density of objects
5. Revise the investigation procedures to reduce error

#### C. Materials

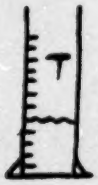
balance (triple beam or two pan with weights)
paper cups
10 and 50 ml graduated cylinders
pencils
large nails
charcoal briquettes
ice cubes
pennies
corks
lead fishing sinkers

#### D. Instructional Activities

1. Weigh the objects for which density will be determined and record the weight in grams.

2. Determine the volume of each object by submerging the objects in water and measuring the milliliters of water displaced. Two methods to do this are illustrated below.

nail
hole
paper cup
water



nail
graduated cylinder
water

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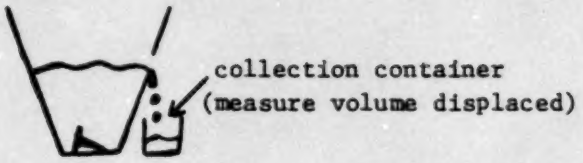


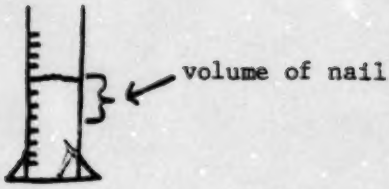


3. Calculate the density of each object using the following formula:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

The data could be organized as follows:

| OBJECT | WEIGHT IN GRAMS | VOLUME IN MILLILITERS | OBTAINED DENSITY (g/ml) |
|---|---|---|---|
| charcoal | | | |
| cork | | | |
| ice cube | | | |
| lead weight | | | |
| nail | | | |
| pencil | | | |
| penny | | | |

4. Compare the obtained densities for the objects with the actual densities below. Calculate the percentage of error using the following formula:

$$\text{Percentage of error} = \frac{\text{Difference between actual and obtained density}}{\text{actual density}} \times 100$$

The data could be organized as follows:

| OBJECT | ACTUAL DENSITY (g/ml) | OBTAINED DENSITY (g/ml) | PERCENTAGE OF ERROR |
|---|---|---|---|
| charcoal | 3.5 (carbon) | | |
| cork | .2 (cork) | | |
| ice cube | .9 (ice) | | |
| lead weight | 11.3 (lead) | | |
| nail | 7.9 (iron) | | |
| pencil | .7 (wood) | | |
| penny | 8.9 (copper) | | |

5. Identify objects for which the percentage of error was large or small. Propose some reasons for the errors or lack of errors.

6. Think about the experimental process and discuss problems, possible sources of error, and solutions to these problems and sources of error. Also identify and discuss conditions for which there is no practical solution.

7. For one object with a high level of error, replicate the investigation incorporating the proposed solutions. The objective of this replication would be to reduce the percentage of error as much as possible.

8. Evaluate the density obtained from the replication investigation in terms of the criterion percentage of error. Discuss the value of carefully conducted investigations and the potential use and misuse of accurate and inaccurate emperical data.

E. Suggested Follow-up Activities

1. Derive the densities of several other objects (e.g., gold ring, piece of aluminium, silver spoon, pumice, coal, quartzite) and compare the results with those found in textbooks or physical science handbooks. A secondary science teacher, college professor in earth science or chemistry, or other science trained professionals might be able to provide assistance.

2. Calculate the densities of various liquids (e.g., water, vegetable oil, salt water) and predict whether objects will sink or float when placed into the liquids. Predictions should be made based on obtained densities determined earlier. Conduct an investigation to test the predictions, and propose a principle for explaining whether objects sink or float when placed in designated fluids.

3. Use the data to construct class graphs and histograms. Concepts that might be explored include graphing skills, identification of trends, arithmetic mean, mode, median, identification of unusual data, slope, normal distribution, and extrapolation. Advanced students might benefit from discussions of elementary statistics as a basis for evaluating individual datum. Simple statistical tests such as chi-square could be demonstrated to establish the concept of significant differences.

F. Information for the Teacher

Some variables that may affect the error of obtained densities include inaccurate equipment, mistakes in graduated cylinder readings, presence of foreign materials (e.g., pencils contain graphite, paint, metal, and rubber; nails are usually composed of an alloy of several metals), loss of water during the collection phase of the water displacement, slight weights of small objects, and lack of significant figures obtained in measurement.

Suggestions for reducing error might include the following:

1. Instruction in reading the meniscus in a graduated cylinder.
2. Use of a more accurate scale. Secondary schools usually have analytical balances that might be used under the supervision of a teacher.
3. Use of pure substances. For a pencil, one might cut off the metal and rubber eraser tip and split the pencil to remove the graphite lead.
4. Measurement might be easier if weights and volumes were determined using multiple identical objects. One might weigh and determine the volume of 50 pennies as opposed to one penny.

Use of a scientific method format is appropriate for the replication investigation. After the students have had experiences with the concepts involved in the lesson and have identified possible variables, an experimental design could be used to improve the procedure.

G. Rationale for the Gifted

Listed below are three principles of differentiation and an identification of the activity components that correspond to each principle.

1. Higher Cognitive Thinking
   - Analysis--comparing of data
     --proposing reasons for error
     --proposing problems in the experimental design
   - Synthesis--proposing solutions to problems in the experimental design
     --establishing an improved experimental design
   - Evaluation--comparison of amounts of error
     --comparison of the results from differing investigation procedures

2. Processes of Learning/Thinking
   - Quantification of data
   - Collection of original data
   - Evaluation of the investigative process
   - Design of an improved experimental design

3. Formal Operational Schemes
   - Separation and control of variables during the replication investigation
   - Hypothetical-deductive reasoning in analysis of problems and their solutions
   - Abstract thinking involved in identifying conditions for which there is no solution and proposing a rationale to explain why

## II. Investigating Starch Location in Plants and Implication for Nutrition

### A. General Purpose

The students will test various plant parts for starch, investigate the relationship between plant part and starch location, and use this information to evaluate foods and diets.

### B. Objectives

The students will:

1. Test plant parts for the presence of starch
2. Compare plant parts related to their presence of starch
3. Determine the source from which common plant foods are derived
4. Generate a hypothesis to explain the location of starch in plants
5. Use the starch location hypothesis to identify foods high in energy
6. Evaluate sample diets or menus for their value in providing energy

### C. Materials

iodine solution
medicine dropper
bean seeds
potatoes
soil
planter cups
variety of student-supplied foods derived from plants

### D. Instructional Activities

1. Provide each student or small groups of students with bean plants, unplanted bean seeds, iodine solution, and medicine droppers. Have the students separate plant parts (e.g., root, stem, and leaf) and test each for starch. A split open bean seed should also be tested. Encourage the students to record their observations. The following format might be useful for some students.

| Plant Part | Description | Reaction to Iodine | Conclusion |
|---|---|---|---|
| Root | | | |
| Stem | | | |
| Leaf | | | |
| Seed | | | |

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Provide each group with a piece of potato. Direct the students to test for starch and add the data to their records.

2. Conduct a class discussion in which the relationship between plant part and starch is established. Efforts should be made to cite data to support conclusions. Conclude the discussion by identifying the plant part from which common plant foods are derived. Some examples might include the following: lettuce-leaf, celery-stem, pea-seed, turnip-tuber.

3. Have the class generate a hypothesis to explain the location of starch in plants (e.g., Starch is found in leaves and roots). Remind the students that starch is a food substance that provides energy for living things. Based on the class hypothesis of starch location and the concept that starch provides energy, challenge the students to identify common foods that are high in energy.

4. Suggest that each student test their hypothesis of starch location and its implication for identifying high energy foods. Students should bring in a variety of foods to test for starch. Leftover cafeteria or lunch box foods could also be used. Encourage each student to keep an accurate record of foods tested, observations, and conclusions.

5. Compile the individually collected data into a class data chart. Discuss the data and conclusions. Where hypotheses were not supported or where there were conflicting results, attempt to identify factors that might explain these conditions. In some cases, it might be necessary to revise hypotheses. If possible, evaluate the test procedures and identify techniques for standardizing the process.

6. Use the data and revised hypotheses to evaluate the energy-producing capacity of sample diets or menus. Some examples might include the weekly cafeteria menus, random selection of lunch box contents, student reports of their breakfast or dinner, and published weight reduction or weight gain diets.

E. Suggested Follow-up Activities

1. Test a variety of fruits for starch and simple sugar. Research the functions of sugar in bodily processes. Evaluate foods that are high in sugar and their value for various purposes.

Simple sugar test: Put a small amount of material in a test tube, add enough Benedict's solution to just cover the material. Heat the test tube in a warm water bath. Interpret the results as follows: Blue - no simple sugar present; Green - a small amount; Yellow - a moderate amount; Brick Red - a large amount.

F. Information For the Teacher

Iodine solution can be used to test for the presence of starch in foods. This test is carried out simply by placing several drops on the surface of the food to be tested. A purple to black color change indicates that starch is present.

One to two weeks prior to teaching this lesson, bean seeds should be planted in pots or cups. Bean seeds are recommended since they germinate and grow quickly.

G. Rationale for the Gifted

Listed below are three principles of differentiation and an identification of the activity components that correspond to each principle.

1. Higher Cognitive Thinking

Analysis -- identifying plant parts from which foods are derived
Synthesis -- describing relationships between starch location and plant part
-- designing revised starch-testing procedures
Evaluation -- determining foods that are high in energy

2. Processes of Learning/Thinking

Collection of original data
Using data to support conclusions
Testing hypotheses

3. Formal Operational Schemes

Hypothetical-deductive reasoning in describing factors that might explain conflicting results
Separation and control of variables in the starch test investigations


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## III. Phosphorus and its Effect on Water Quality

### A. General Purpose

The students construct aquaria, make observations, and investigate the effects of phosphorus.

### B. Objectives

The students will:

1. Construct two identical aquaria
2. Collect base line data and make observations
3. Introduce phosphorus into one of their aquaria and observe any changes
4. Measure and compare the levels of dissolved oxygen and turbidity
5. Evaluate the effects of excessive phosphorus on an aquatic community
6. Research the phosphorus cycle in aquatic environments and identify phosphorus sources
7. Propose solutions to the high phosphorus problem and discuss advantages and disadvantages of these solutions

### C. Materials

aquaria tanks
water and plants from aquatic environments
dissolved oxygen test kit
high phosphate fertilizer

### D. Instructional Activities

1. Allow the students to collect water and aquatic plants from an aquatic community such as a pond, stream, or estuary. Where such a student collection project is not possible, provide these materials. Divide the students into small groups of four to six students and assign each group to construct two identical aquaria.

2. Each team of students should make observations of their aquaria for several days. Particular attention should be devoted to describing physical appearances, determining dissolved oxygen (i.e., use a dissolved oxygen test kit), and measuring turbidity. If possible, students should design their own quantitative measures of turbidity.



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3. After several days, introduce a high phosphorus fertilizer (e.g., 0 - 46 - 0) into one of each team's aquaria. Since only an increase of several parts per million are required to induce an algae bloom, use a relatively small amount of fertilizer. For aquaria with a one- to two-gallon volume, this amount is about one gram. Every effort should be made to identify all other variables and hold these constant throughout the investigation. Variables that might be identified include temperature, light, and amount of water. To obtain results quickly, all aquaria should be placed near a light source.

4. Students should continue to make daily observations of their aquaria. After an algae bloom forms, encourage students to note any changes in appearances, dissolved oxygen, and turbidity levels. This data might be plotted against time on a graph or chart.

5. Discuss the effects of excess phosphorus on an aquatic community. Focus particularly on the levels of turbidity and oxygen and the possible short-term effects on light levels and respiration rates. Students might also speculate on the long-range effects to the environment if high levels of phosphorus were introduced into the local water shed.

6. Evaluate the effectiveness of this investigation. Included might be methods of quantifying data, inability to control all variables, techniques used to manipulate the data, and the appropriateness of conclusions. Where problems are identified, design procedures to modify and improve the investigation.

7. Students should conduct research projects to learn about the phosphorus cycle in an aquatic environment and identify natural and artificial sources of phosphorus. This information should be used to discuss the phosphorus cycle, its importance to the food web, the advantages and disadvantages related to reducing, maintaining, or increasing present phosphorus levels, and possible solutions to the phosphorus problem.

E. Suggested Follow-up Activities

1. Conduct an investigation to determine the effects of adding various products with high and low levels of phosphorus to an aquatic community. Attempts should be made to manipulate only the type of product introduced. All other variables (e.g., amount of product added, light levels, temperature, organisms, water source) should be controlled. Collect data related to physical appearances, oxygen levels, and turbidity. Evaluate the use of these products in terms of their effects on the local aquatic community.

2. With the help of a secondary chemistry teacher, college chemistry professor, or professional chemist, conduct a qualitative and quantitative analysis of phosphorus in a variety of home compounds. Use this information to extend the natural and artificial sources of phosphorus identified earlier. Determine the benefits and deleterious aspects of using these products.

F. Rationale for the Gifted and Talented

Listed below are three principles of differentiation and a description of the activity components that correspond to each principle.

Higher Cognitive Thinking
- Analysis -- describing aquaria appearances and properties
- Analysis -- identifying all variables in the phosphorus investigation
- Synthesis -- designing quantitative measures of turbidity
- Synthesis -- designing procedures to improve the investigative process
- Evaluation -- comparing the investigative processes
- Evaluation -- discussing the appropriateness of conclusions

Processes of Learning/Thinking
- Quantification of data
- Graphing data
- Library research skills

Formal Operational Schemes
- Separation and control of variables in the phosphorus investigation
- Hypothetical-deductive reasoning in describing the effects of phosphorus on aquatic communities

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